SIFCON-A High Performance Concrete - Experimental Investigations

R.G. Sonone, Sanjay Sharma, H.K. Sharma

Abstract*: This paper addresses the development of High Performance Concrete in the past along with the experimental work on properties of Slurry Infiltrated Fibrous Concrete (SIFCON). Slurry infiltrated fibrous concrete has high strength, large ductility and good performance under seismic excitations. There is an increase in numbers of structures testified by the recent symposiums and conferences held on HPFRC. Now presently investigations are being carried out to suggest recommendations for the design of HPFRC structures. SIFCON consist of cement slurry and different types of steel fibers. It is observed that with the increase in percentage of steel fibers there is an improved static, dynamic and mechanical properties of concrete. Steel fibers also act as crack arrester and improve durability. In the present study, it is observed that at 9% fiber content the compressive strength, split tensile strength and flexural strength is optimum.

Keywords: High performance concrete, SIFCON, HPFRC, FRC.

I. INTRODUCTION

For over ten years since 1995, great efforts have been taken at national and international level for practicing High-Performance Concrete technology to increase the service life of civil engineering structures like pavements, tunnel, high rise buildings and bridges.

Generally, HPC will have a low water-cement ratio around 0.4.These low water-cement ratio concretes often depend on the effective use of admixtures to get high workability which is another common characteristic of HPC mixes. [1].

Several definitions have emerged over the years to acquaint the engineering community and concrete industry with HPC. According to ACI, "HPC is defined as concrete which meets special combinations of performance and uniformity requirements that are not achieved by using conventional constituents and normal practices of mixing, placing and curing" (ACI116R). The Federal Highway Administration (FHWA) promoted "HPC in the 1990's by defining it in 1996 using four durability and four strength parameters". "Associated with each definition parameter were performance criteria, testing criteria, testing procedures to measure performance, and recommendations to relate performance to adverse field conditions" [1]. The National Concrete Bridge Council has drafted a definition for HPC as, "Concrete that attains mechanical, durability or constructability properties exceeding those of normal concrete." Section 3 of this Designers' Guide provides information relative to current definition and performance characteristics of HPC [1].

II. DEVELOPMENT OF HIGH-PERFORMANCE CONCRETE

It required almost one decade for the development High performance concrete having compressive strength up to 100 N/mm2. Concrete having compressive strength of 100 N/mm^2 was supposed to be the maximum strength .This is because the strength of the aggregate was a limiting criterion. There is a major progress in the recent decades in the development of fiber reinforced concrete and high performance fiber reinforced concrete. But due to the composition of fiber reinforced concrete there are certain limitations in its development. The maximum quantity of steel fiber volume fraction is limited to approximately 2% due to the constraint of workability. This low volume fiber content mainly provides post cracking ductility and energy absorption. Due to this reason of FRC having lower workability when the fiber content increases, it has provided a necessity for development of a real high performance concrete. Hence to overcome the limitation of lower workability the new concepts of high performance fiber reinforced concrete were developed to increase the fiber volume, efficiency and also achieve the workability. HPFRC is a new class of fiber reinforced concrete which shows a behavior particularly desirable for design of earthquake resistant structures. HPFRC exhibits increasing strength ductility and energy absorption [2]-[3]. Different types of High performance fiber reinforced cement based composites are named given as below. [4]

SIFCON- (Slurry infiltrated fibrous concrete)
SIMCOM - (Slurry infiltrated mat concrete)
DSP - (Densified with small particle systems)
MDF- (Macro defect free cements)
RPC - (Reactive powder concrete)

A. SIFCON – It is the material developed in nineties in which the fibers are placed and then the space between the fibers is filled with cement based slurry. Hence it was possible to increase the volume of fibers up to 12% which is almost ten times more than fiber content in FRC. Due to this large strain capacities 10 to 15% and a comparatively high strength 120 to 140 MPa can be achieved. But still Limitation is that the fiber gets HPFRC is more costly [5].

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B. HPC- Standard design recommendations-

There are no internationally accepted design recommendations regarding high performance fiber reinforced concrete and this is mainly due to following reasons.

1. There is not sufficient information regarding the properties of HPFRC such as durability of HPFRC. If there is a requirement of large covers then in such case the slender and thin HPFRC structural elements may not be suitable.[06]
2. The international codes are still not modified for incorporating the use of FRC and HPFRC. Still there needs a lot of work to be done regarding incorporating the design rules with respect to shear reinforcement taking the advantage of Steel fibers in FRC and HPFRC. Efforts are also required for development of suitable code which will enable the combined use of traditional RCC and FRC and HPFRC.
3. Investigations are required to check the possibility of design of FRC and HPFRC along with the traditional RCC. There are certain unaddressed issues like FRC contains course aggregate and large Steel fibers while in HPFRC short Steel fibers and only fine aggregates are used.
4. Other issue is regarding the orientation of fibers which causes lot of variation in the properties of FRC and HPFRC.

III. EXPERIMENTAL INVESTIGATIONS

The experimental work was conducted by casting cubes of size 100 X 100 X 100 mm to determine the compressive strength, the beam of size 100 X 100 X 500 mm to determine the flexural strength and cylinder of size 100 mm diameter and 200 mm height to determine the split tensile strength. Steel fibers were dispersed as per the pre-decided volume fraction in a random manner and platform vibrator was used to ensure proper compaction and penetration of the slurry into the fibers. After 24 hours the cubes where removed from the mould and curing was carried out for 7 days and 28 days.

A. CONSTITUENT MATERIALS

1. Cement

Ordinary Portland cement of 43 grade was used for the experimental work. The cement was procured and stored in airtight container so that the deterioration of quality is prevented. The cement was tested for the physical properties and the properties are listed in table I

Table- I: Physical Properties of Cement: 43Grade OPC

Sr. No.	Characteristics	Observed Values	Recommendation Value as per IS:8112
1.	Normal Consistency (%)	30	-
2.	Specific Gravity	3.09	3.15
3.	Soundness (mm)	2.2	10 (Maximum)
4.	Initial Setting Time in minutes	80	Not less than 30 minutes
5.	Final setting time in minutes	187	Not more than 600 minutes
6.	Fineness (Sieve Analysis)	2.35	Not more than 10
6.	Compressive Strength (N/mm^2) i) 168 hours	28.5	Not less than 23
	ii) 672 hours	46.23	Not less than 43

2. Fine Aggregate

Natural river sand was used confirming to zone II as per IS 383 – 1970. The specific gravity of sand was 2.67, fineness modulus was 2.73 and water absorption was 2.15%

3. Silica Fume

Silica fume having specific gravity 2.02 and specific surface area 2200 m^2/kg was used. Properties of silica fume are presented in table II. Silica fume was in a dry powder form and it improves the performance of mortar. Silica fume optimizes the particle packing in the mortar mixture and chemically it acts as a highly reactive pozzolana

Table-II: Properties of silica Fume

Sr. No.	Property	Microsilica (Silica Fume)
1.	Specific gravity	2.6
2.	Density	1.01g/cc
3.	Silica as $Si0_2$	95.86%
4.	Iron as Fe_20_3	0.34%
5.	Aluminum as Al_20_3	0.15%
6.	Calcium as Cao	0.35%
7.	Magnesium as Mg0	1.10%

4. Water

As prescribed by IS: **456-2000** potable water which is free from deleterious material and fit for drinking purpose has been used for mixing as well as curing of specimens in the experimental work.

5. Steel Fibers

Zig zag (wave shape) Steel fibers having high tensile strength and which can be easily dispersed and integrated with concrete have been used. Properties of steel fibers are listed in Table III.

Table- III: Properties of Steel Fibers

Sr. No.	Description of Property	Unit	Values
1	Length	mm	40 and 50
2	Diameter	mm	0.5
3	Aspect Ratio	--	80 and 100
4	Tensile Strength	N/mm^2	1100
5	Carbon Content	percentage	0.82
6	Density	g/cm^3	7.85

6. Super plasticizer

Super plasticizer was used to improve the workability of SIFCON. Superplasticizer manufactured with trade name Glenium sky 777 by BASF was used in the present study. This superplasticizer is developed using nanotechnology based on second generation polycarboxylic ether polymers

IV. DESIGN OF SIFCON

The cement based slurry- mortar plays an important role in SIFCON. Effective transfer of forces between Steel fibers and mortar decides the behaviour of SIFCON specimen. Volume fraction of fiber is kept as 3%, 5%, 7%, 9% and 11%. Water binder ratio was kept as 0.4 and the dose of superplasticizer was 1.2 % by weight of cement and silica fume. The dose of superplasticizer was properly decided to have easy infiltration of cement slurry in the fibers. Initially the fibers are placed in the mould in proper volume fraction and the cement slurry is infiltrated thoroughly through the densely packed fiber filled moulds. The two layer technique was adopted for infiltrating mortar slurry into the packed fibers. This proved very effective for casting the SIFCON specimens and it was easier than a single layer technique. It is very useful when high volume content of steel fibers are used. In two layer technique, initially the mould is filled with fibers up to half depth and then the cement slurry is infiltrated up to this half depth of the mould. The mould is placed on the platform and vibrated. This process is again repeated until the entire mould is filled with the specific fiber content. It was observed that up to 6% of fiber volume fraction, no vibration was required but light vibration for 10 seconds was necessary when the volume of fiber was 9% and intense vibration was necessary for about 20 seconds when the fiber volume fraction was 11%, so that the SIFCONs slurry infiltrates completely into the fibers placed in the mould. Weight of Steel fibers to be added in each mould depends on the size of mould, density of fibers and percentage volume fraction of steel fibers used. The specimen where removed from the mould after 24 hours and they were placed for curing in a water tank for 7 days and 28 days.

V. COMPRESSIVE STRENGTH TEST

The compressive strength test was conducted as per the provisions given in BS 1881- Part 116-1983[07] by using 100 mm cube mould. The compressive strength is an average of three specimens for each mix. Please refer Fig.1 and Fig.2 respectively.

Figure 1. Cube Comp Strength in MPa at 28 Days for different SIFCON % (AR80)

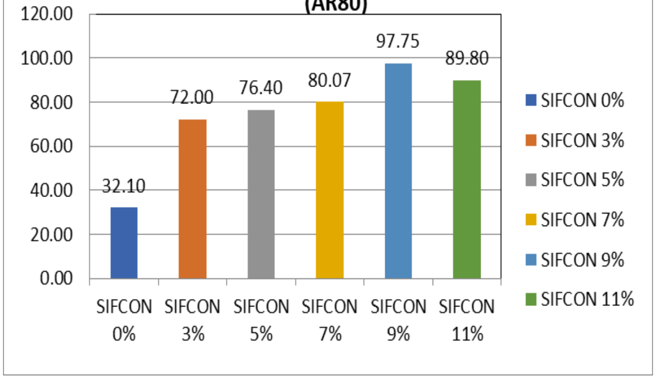
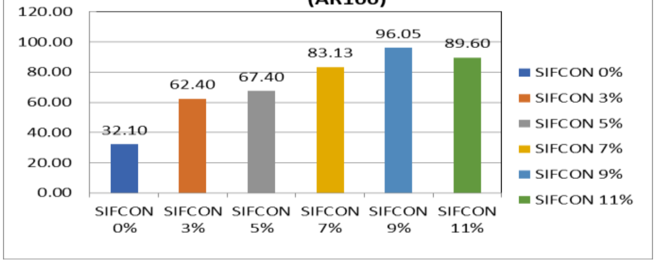


Figure 2. Cube Comp Strength in MPa at 28 Days for different SIFCON % (AR100)



1. Split Tensile Test

The split tensile test was conducted as per ASTM C 496-96[08] on cylindrical moulds specimen. The split tensile test was conducted on specimen after 7 days and 21 days of water curing. For each mix three specimen where tested and the average is recorded. Fig. 3 and Fig.4 respectively shows the graphs of the same.

Figure 3. Cylinder Split Tensile Strength in MPa at 28 Days for different SIFCON % (AR80)

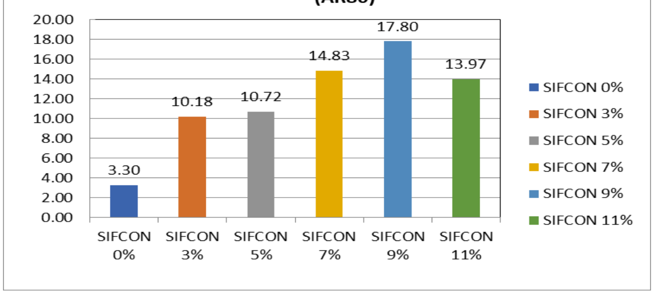
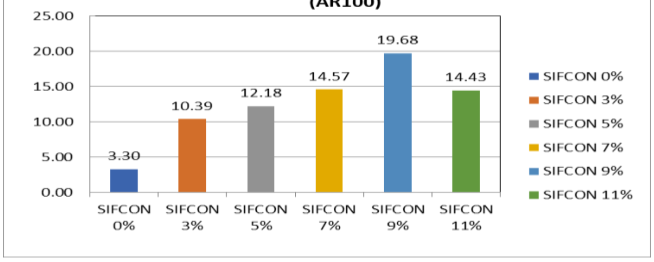


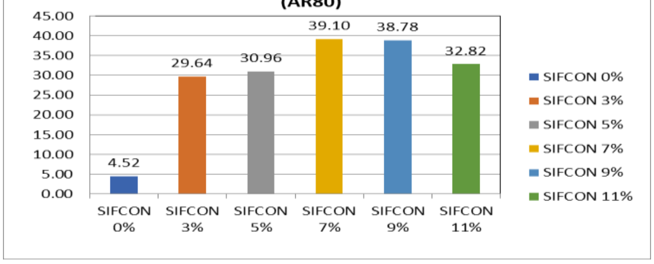
Figure 4. Cylinder Split Tensile Strength in MPa at 28 Days for different SIFCON % (AR100)



2. FLEXURALSTRENGTH

This test was implement by specimens with prism in shape (100×100×400 mm) at (28) days of treatments based on ASTM C-78, 2002 [09]. A flexural strength results for different mixtures are presented in Figure 1 4. The specimen strength results showed that there is an increase due presence of steel fiber. The steel fiber enhances the tensile strength of concrete. Please refer Fig.5 and Fig.6 respectively.

Figure 5. Flexural Strength in MPa at 28 Days for different SIFCON % (AR80)



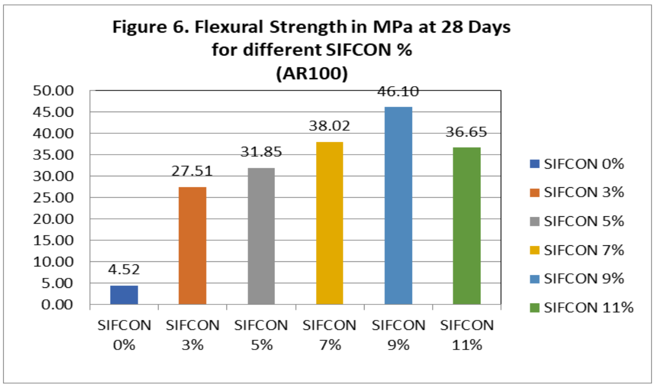


Figure 6. Flexural Strength in MPa at 28 Days for different SIFCON % (AR100)

VI. CONCLUSION

1. It has been observed that the compressive strength of SIFCON with fibers aspect ratio 80 increases with increase in the fiber percentage, the compressive strength at 3% fiber is 72.00 Mpa while as the fiber percentage goes on increasing from 3, 5, 7, 9 the compressive strength increases to 76.40, 80.07 and 97.75 Mpa. The maximum compressive strength is obtained for the fiber percentage 9% as 97.75 Mpa.
2. For the SIFCON having fibers with aspect ratio 100, the compressive strength with 3% fibers was recorded as 62.40 Mpa while the compressive strength increases with increase in fiber content. For 5% 7% and 9% the compressive strength increases to 67.4 Mpa, 83.13Mpa and 96.05Mpa respectively.
3. For the aspect ratio 80 and 100, it is observed that the compressive strength decreases at the fiber content 11.00%, this might be due the difficulty in penetrating the mortar in the fiber mesh uniformly when the fiber content increases beyond 10%.to 11 %.
4. Split tensile strength with 3% fiber having aspect ratio 80 is 10.18Mpa and it goes on increasing up to 17.80 Mpa. Similarly for the fibers with aspect ratio 100 the split tensile strength at 3% fiber content is recorded as 10.39 Mpa and it reaches to 19.68Mpa for the fiber content 9%.
5. The strength of SIFCON with fibers having aspect ratio 80 and 3% fibers the flexural strength recorded is 29.64 Mpa while the Maximum strength obtained is at 9% fiber volume and it is 38.78Mpa. For the fibers having aspect ratio 100 and 3% fiber volume the flexural strength obtained is 27.51Mpa and it reaches 46.10 Mpa at 9% fiber content.
6. In case of split tensile strength and flexural strength the difference of increase in strength at 7 days curing and 28 days curing is found to be marginal.
7. In the present study, it is observed that at 9% fiber content the compressive strength, split tensile strength and flexural strength is optimum.

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REFERENCES

1. High performance concrete structural designers' guide, First Edition March 2005, U.S. Department of Transportation, Federal Highway Administration.
2. Naaman, A. E.. SIFCON: Tailored Properties for Structural Performance, High Performance Fiber Reinforced Cement Composites, E & FN Spon, pp. 18-38,1992.
3. Vojko Kilar and N. Krstulovič-Opara, Seismic behavior of high-performance fiber reinforced composite frames, International Journal of IT in Architecture, Engineering and Construction, Vol. Issue 3, pp. 225-238, September 2003.
4. G. L. Guerrini, "Applications of High-Performance, Fiber-Reinforced Cement-Based Composites," Applied Composite Materials 7: 195–207, 2000.
5. Joost C. Walraven High performance fiber reinforced concrete: progress in knowledge and design codes Materials and Structures (2009) 42:1247–1260W.
6. Scheydt J, Herold G, Mu¨ ller HS (2008) Long term behaviour of ultra high performance concrete under the attack of chlorides and aggressive waters. In: Proceedings of the second international symposium on ultra high performance concrete, Kassel, Germany, 5–7 Mar 2008, pp 231–240.
7. BS: 1881- Part:, 116-1983, "Method for determination of Compressive strength of concrete cubes", British Standard Institution.
8. ASTM C 496-96" Standard Test method for splitting tensile strength of cylindrical concrete specimens".

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